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STRESS CRACKS and BREAKAGE in ARTIFICIALLY DRIED CORN

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SUMMARY

Shelled corn dried with heated air (140° to 240° F.) was two to three times more susceptible to breakage than the same corn dried with unheated air. Stress cracks (endosperm fissures), while practically nonexistent in crib-dried ear corn, were found in all samples of shelled corn dried artificially and accounted for much of the increased susceptibility to breakage. Such breakage contributes to downgrading of corn and to its susceptibility to molds and insect damage.

Other factors involved in breakage of corn, as indicated by laboratory breakage tests, are field shelling at high moisture levels and handling at low moisture levels or at low temperatures. Corn harvested at initial moistures near 30 percent broke easier than that harvested at 20-percent moisture. The amount of physical damage to the corn--broken, mashed, or scratched kernels--inflicted by the field sheller was higher in the wetter corn. Breakage increased as the amount of sheller damage increased.

Drying speed, expressed in terms of moisture loss in percentage points per hour, was the most significant factor in stress-crack development. The number of stress cracks increased with increased drying temperatures and airflow rate, both contributors to drying speed. The amount of drying--the number of percentage points the moisture content is reduced--as well as the speed appears to affect stress-crack development. Puffing of kernels--more damaging than stress cracks--occurred, even though the number of stress cracks was reduced, when high-moisture corn was dried at drying speeds exceeding about 8 to 10 percentage points per hour. The crowns of puffed kernels were almost completely removed in breakage tests.

Most of the stress cracks were formed while corn was drying through the moisture range from 19 to 14 percent, according to laboratory and preliminary field tests. Rapid cooling of the dried corn added to the drying stress already present and increased the number of stress cracks.

Stress-crack evaluation can be useful not only in detecting corn that has been dried rapidly, but also in predicting increases in fine material that may be expected from breakage during handling.

Stress cracks in artificially dried corn are reduced (1) at slow drying speeds (especially through the range of 19 to 14 percent moisture) and (2) when cooling of the dried corn is delayed until after a tempering period.

No attempt was made to relate the results of laboratory breakage tests to the amount of breakage that might occur in handling operations common to the grain trade. However, the tests show that increased breakage may be expected if corn is (1) artificially dried with heat, (2) field shelled at high moisture levels, (3) handled at low moisture levels or at low temperatures.

STRESS CRACKS AND BREAKAGE IN ARTIFICIALLY DRIED CORN

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INTRODUCTION

The growing mechanization of American agriculture includes use of the field sheller for harvesting corn. Field-shelled corn generally is too moist for ordinary storage without artificial drying. Increased use of artificial drying has paralleled the increased use of field shellers. Artificially dried corn presents new problems to corn millers, 1/ grain warehousemen, and grain exporters 2/.

This publication, which replaces AMS-434, "Stress Cracks in Artificially Dried Corn," reports on both the formation of stress cracks and increased breakage susceptibility in artificially dried corn. Stress cracks are fissures in the endosperm, or starchy inside of the kernel; the seed coat is not ruptured. Corn that is susceptible to breakage accumulates additional fine material each time it is handled. Since the fine material is included as foreign material in the grading standard, breakage contributes to downgrading of corn. Cracked and broken kernels within batches of corn make aeration difficult and invite attacks by molds and insects.

The work reported here is part of a continuing USDA-Purdue University research effort to develop improved methods and techniques for holding down costs and losses in marketing artificially dried corn.

TESTS CONDUCTED

Tests to evaluate the effect of artificial drying on the suitability of corn for various commercial and industrial uses have been conducted over four crop years (1959-1962). Field tests were made in a continuous-flow tower-type dryer designed mainly for use at country elevators (fig. 1). A grain gate was installed between the heating and cooling sections, and the same dryer was used for batch tests. The four series of tests with the dryer are designated "field tests."

1/ Wichser, W. R. What Agricultural Engineers Can Do For the Wet and Dry Corn Milling Industry. Paper No. 61-903, presented at the Winter Meeting of the American Society of Agricultural Engineers in Chicago, Ill., Dec. 12-15, 1961.

2/ Richards, R. W. New Export Corn Grade? Grain and Feed Journals Consolidated, Vol. 119, No. 2 (Jan. 24, 1962).

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Figure 1.--The experimental grain dryer used for "field tests."

The following variables were investigated in the field drying tests:

Drying treatment	Treatment level
Initial moisture content of corn, % ...	20
....	30
Temperature of the drying air, °F......	140
....	190
....	240
....	290 (1962 tests only)
Airflow rate, cfm/bu..................	35 (1961 tests only)
....	67
Drying method.........................	Continuous flow
....	Batch

The first year's tests were mainly exploratory and are not included in the table. Three commercial corn hybrids, all adapted to Indiana, were used for the tests. The corn was harvested with a field sheller, and dried to a final moisture content of about 14 percent.

Small samples of each test lot were also dried to about 14 percent in shallow screen-bottomed trays with forced air at room temperature. These samples, designated as initial or control samples, were used to evaluate the changes associated with the heated-air drying treatments.

The breakage data from the 1960, 1961, and 1962 test series are reported. The data reported on stress cracks are from the 1961 and 1962 tests. Twelve or more field drying tests were conducted each year.

Tests were conducted in the laboratory to augment the field studies. In 1961, a series of samples was dried in a small laboratory dryer (fig. 2). Air at 160° F. was passed through shallow layers of corn at a velocity of about 120 feet per minute. The corn was dried from an initial moisture content of about 22 percent. Different samples were dried to moisture levels of 18, 16, 14, 12, and 10 percent with heat and, if needed, further dried to 12 percent with room air. Another group of samples was first dried with room air to selected moisture levels, then dried from 2 to 5 percentage points with heat, and further dried to 12 percent with room air if needed. A part of the sample was examined for stress cracks after each increment of drying, to determine when the stress cracks developed. The sample examined was divided, and half was put into a vacuum bottle to cool slowly. In most tests, the other half of the sample was divided and one part examined for stress cracks while hot and the other part cooled rapidly before the stress cracks were counted. All samples were re-examined for stress cracks 24 hours later.

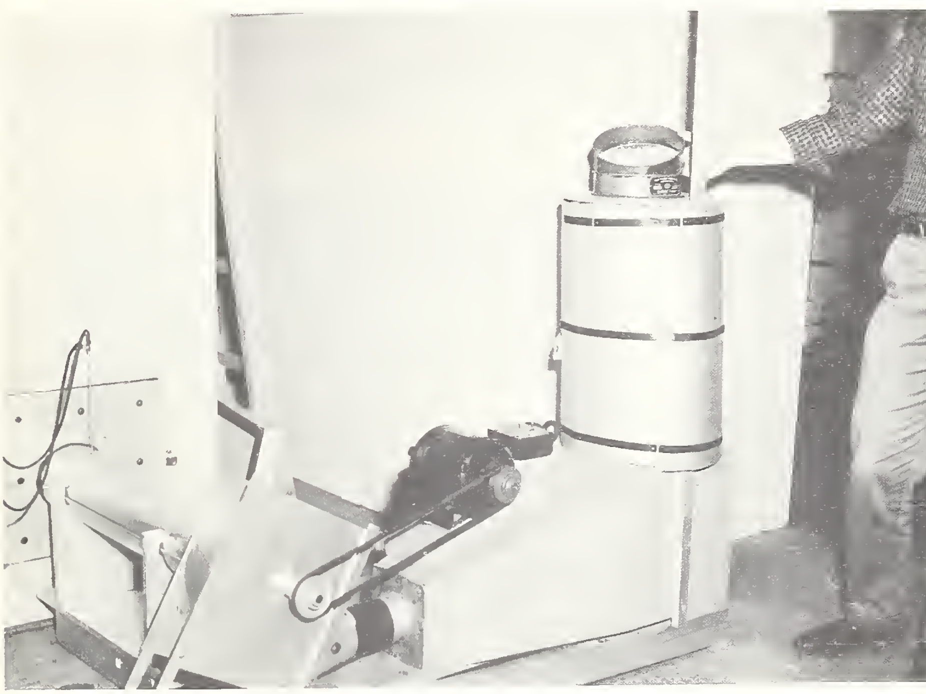

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Figure 2.--Drying air was forced through thin layers of corn in the laboratory tests.

In 1962, a series of tests was conducted in the laboratory with corn at the same levels of moisture and drying-air temperature used in the field tests. At each moisture and temperature, simulations of three different drying methods --crossflow, counterflow, and concurrent flow of air, in relation to the

movement of the corn--were tested. Part of each sample was rapidly cooled with forced air and part slowly cooled in a vacuum bottle. Breakage tests and stress-crack evaluations were made on each sample.

Miscellaneous laboratory tests included a small test series comparing stress-crack development in corn dried on the ear with that in corn dried in shelled form. Other tests were made to explore treatments to reduce the development of stress cracks.

INCIDENCE OF STRESS CRACKS

The shelled corn that was artificially dried exhibited characteristic cracks or checks. The cracks developed in the kernel endosperm; the seed coat was not ruptured. When the seed coat was removed by soaking or scraping, the endosperm broke easily at the stress cracks.

Stress cracks are readily visible under bright light and were evaluated in these tests by a simple candling process (fig. 3) (see appendix for details of procedure). The stress cracks were classified into single, multiple, or checked, according to the pattern formed in the kernel (fig. 4). The first indication of drying stress was a single crack, usually extending from the tip toward the crown of the kernel and visible on the side of the kernel opposite the germ. As stress increased, multiple cracks appeared, some kernels developing a checked or crazed appearance.

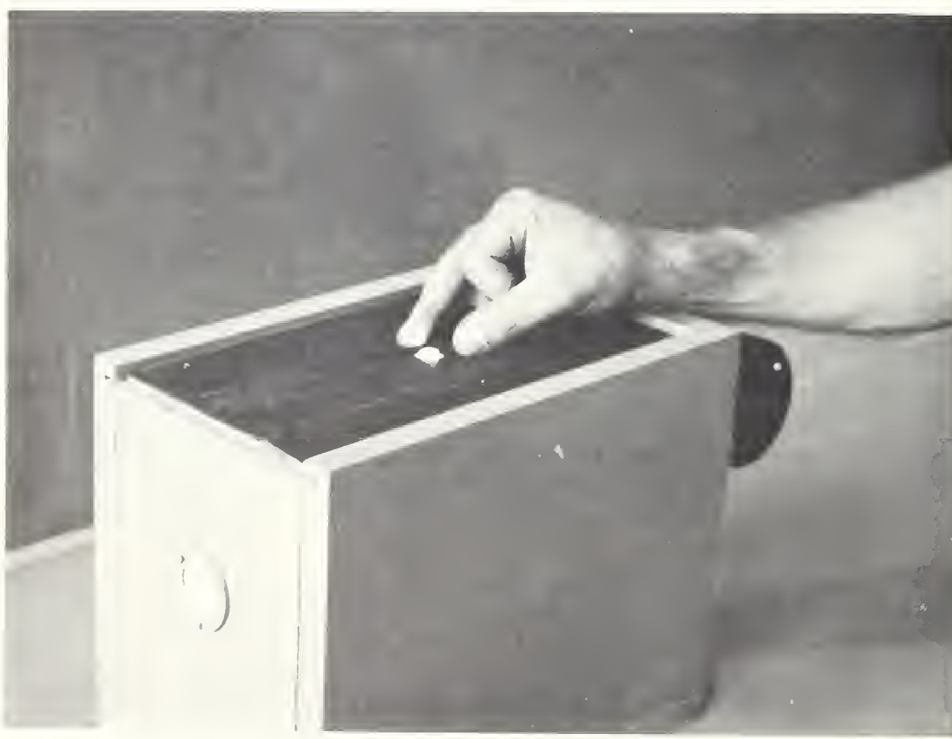

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Figure 3.--The candling device used to examine corn for stress cracks.

In the field drying tests conducted over a 3-year period, about 95 percent of the dried corn had stress cracks. In 1961 and 1962, checked kernels (defined as having two or more stress cracks intersecting) were classified separately and not included with the multiple stress cracks (see appendix table 2). The number of stress cracks was related to differences in the drying treatments when based on the number of checked kernels. Corn dried from near 30 percent initial moisture had 32.9 percent checked kernels, while that dried from near 20 percent had 22.8 percent. Drying-air temperatures of 140° , 190°, and 240° F. resulted in 20.2, 29.6, and 33.9 percent checked kernels, respectively. In 1961, each drying treatment was repeated, using only half the airflow rate used for the other tests. This reduction of airflow resulted in reducing the checked kernels from 20.0 to 15.7 percent.

To determine if the corn used in the drying experiments was typical, 10 samples of dried corn were obtained from 10 farmers or elevator operators. The corn dried in either batch or continuous-flow dryers all showed 50 percent or more of the kernels with either multiple or checked stress-crack patterns. The samples from four in-storage drying systems using low temperatures had very few checked kernels.

AMOUNT OF BREAKAGE

The susceptibility of the dried corn to breakage was determined on small samples in laboratory breakage devices (fig. 5). The equipment is described and the procedure detailed in the appendix. The breakage reported is the amount of fine material that will pass through a 12/64-inch round-hole sieve after treatment in the laboratory test. No attempt was made to relate the breakage reported to that occurring in normal handling operations in the grain trade. In fact, other factors that contribute to the breakage in actual practice were held constant in these tests, in order to measure differences in the drying treatments alone.

Shelled corn dried with heated air was two or three times more susceptible to breakage than the same corn dried with unheated air (fig. 6). Corn dried from 30 percent moisture was more susceptible to breakage than that dried from 20 percent. As the drying-air temperature and airflow rate were increased, the shelled corn became somewhat more susceptible to breakage. The method of drying--continuous-flow or batch--had the least effect (see appendix table 1).

In the laboratory tests, and to a lesser extent in field tests, where 290° F. drying air was used to dry 28-percent corn, the kernels were puffed. The crown of the kernel was affected most, and the dents in the crown were almost completely inflated. When breakage tests were made on the puffed kernels, the crowns were removed completely (fig. 7). This treatment revealed cavities in the center of the kernel similar in appearance to those reported by Pickett and co-workers 3/. The breakage in samples with puffed kernels was somewhat greater in amount, and the fine material more flour-like in appearance, than in samples dried at more moderate temperatures.

3/ Pickett, L. K. Accelerated Drying of Corn. Paper No. 62-101, presented at the annual meeting of the American Society of Agricultural Engineers in Washington, D. C., June 17-20, 1962.

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Figure 4A.--Types of stress cracks in dried corn: Whole kernels (top); single stress cracks (bottom). See also figure 4B.

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Figure 4B.--Types of stress cracks in dried corn: Multiple stress cracks (top); checked or crazed kernels (bottom). See also figure 4A.

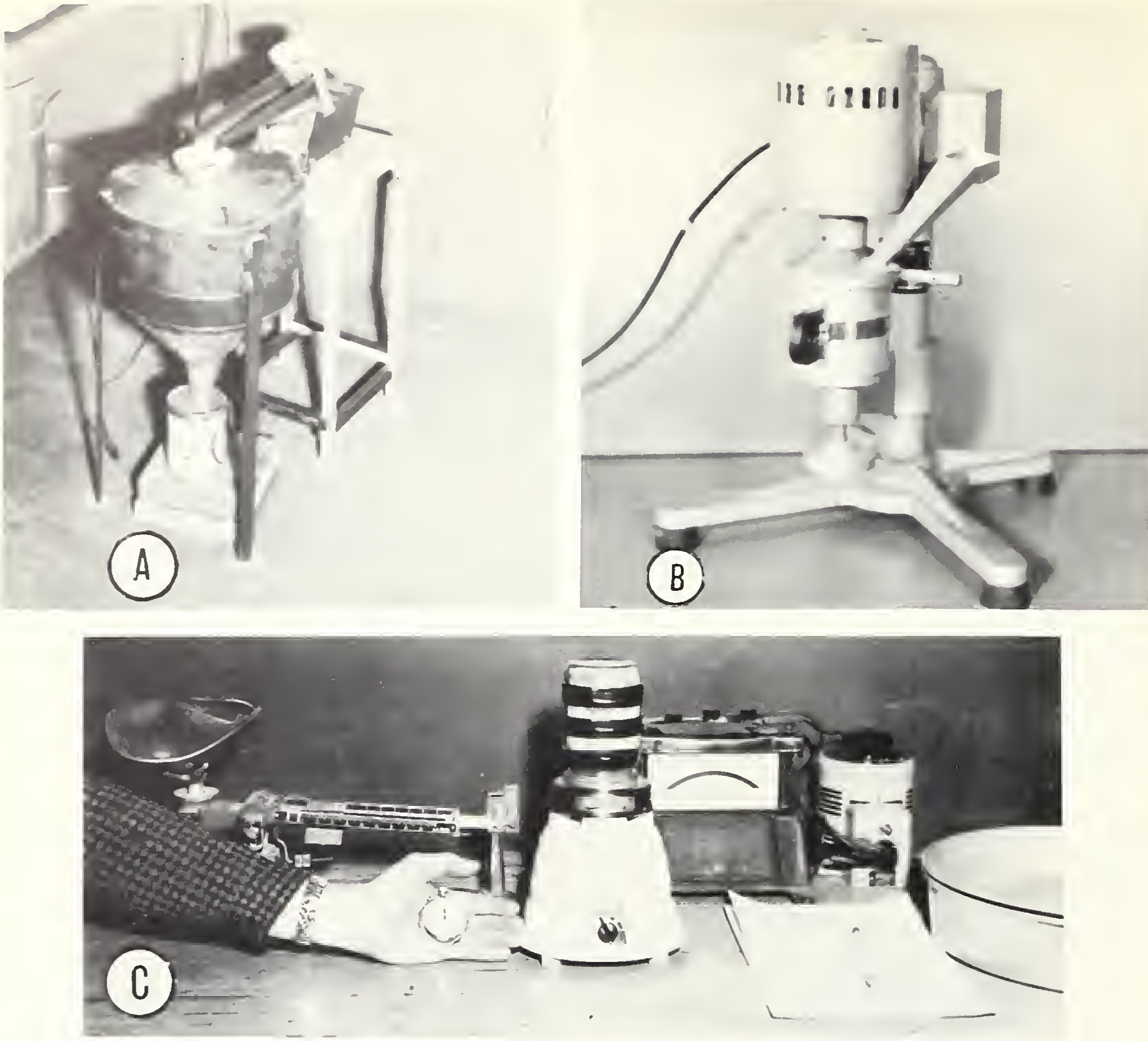

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Figure 5.--The three breakage testers used: A. Modified peanut splitter. B. Commercially built tester. C. Modified food blender and accessory items.

Field Shelling Increases Breakage

For the corn field-shelled at 30-percent moisture, machine harvesting contributed about as much to the breakage as artificial drying. Over 2½ times as many corn kernels were damaged--broken, mashed, or scratched--when harvested at 30 percent moisture as when harvested at 20 percent. The relationship between the percentage of damaged kernels and the breakage after drying with unheated air is shown in figure 8. Fine material was removed from the test sample by screening with a 1/4-inch sieve before the breakage tests were made. The material removed averaged 3.5 percent in the 30-percent corn and 1.9 percent in the corn harvested at 20-percent moisture. This would normally be included in the breakage.

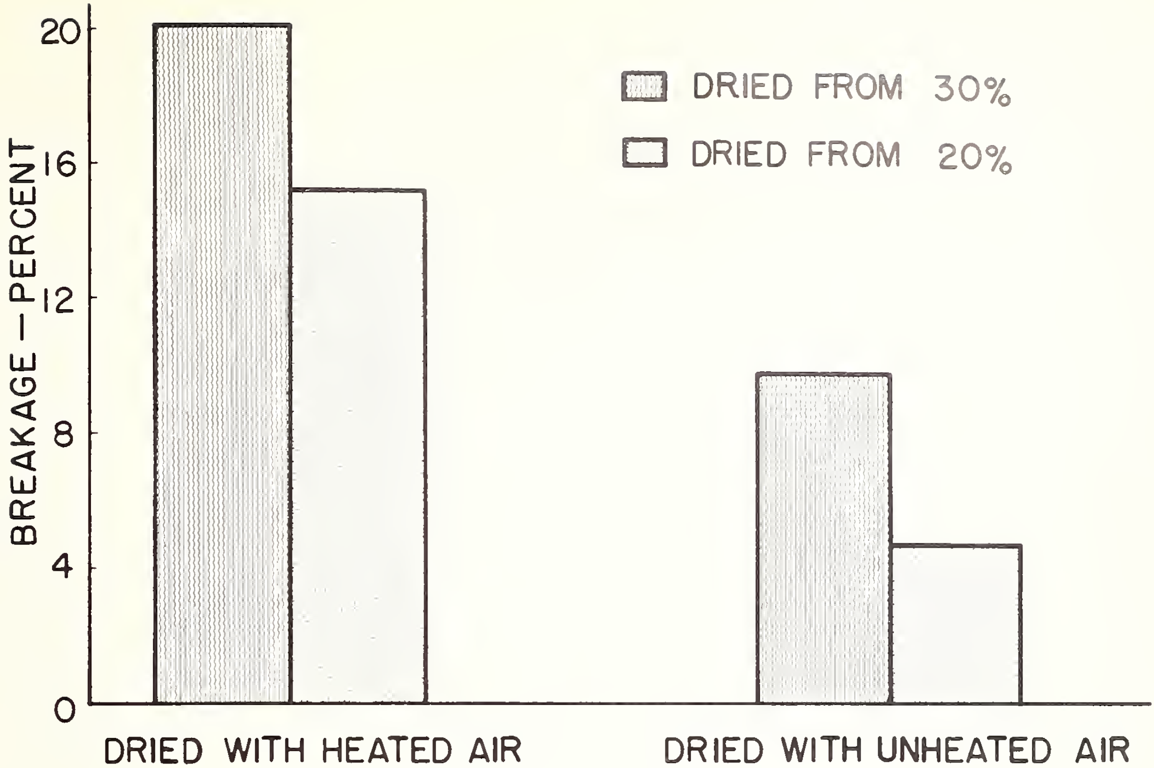

Figure 6.--Breakage in shelled corn dried with heated and unheated air.

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Figure 7.--Puffed kernels before and after breakage tests. The crown was broken off in the tests, revealing endosperm cavities.

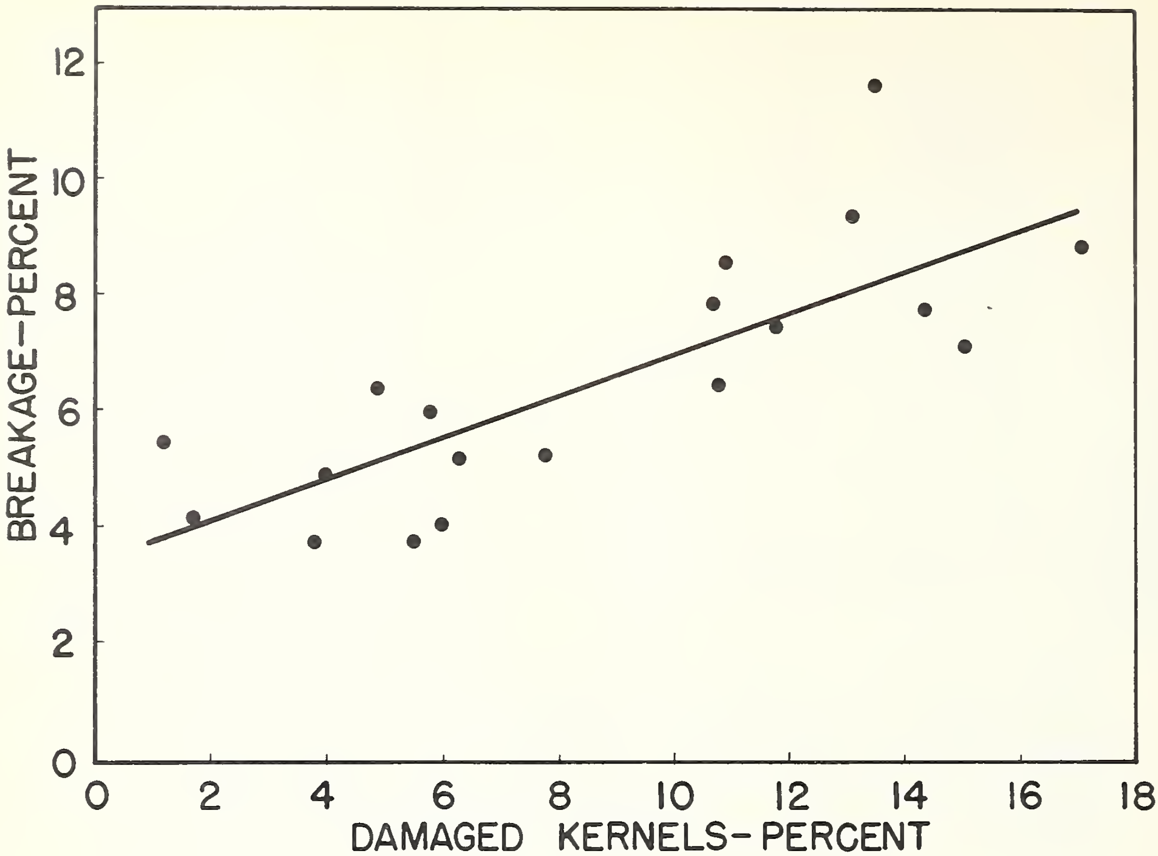

Figure 8.--Relation between sheller damage and breakage in corn dried with unheated air. The correlation coefficient between these two variables is 0.79 and the standard error from the regression is $\pm$ 1.35 (% breakage).

The effect of field shelling on breakage was confirmed also by comparisons of breakage in field-shelled corn with that in hand-shelled for some of the laboratory tests. Field-shelled corn had about twice the amount of breakage after drying.

RELATION OF STRESS CRACKS TO BREAKAGE

As the number of stress cracks in the corn increased, the susceptibility to breakage increased, as determined by the laboratory breakage tests. Figure 9 shows this relationship in terms of increase in breakage due to drying. The amount of breakage in the control sample dried with unheated air was subtracted from that in the sample dried with heated air, and the difference plotted against the percent of checked kernels. There are factors other than drying involved in corn breakage, as discussed earlier.

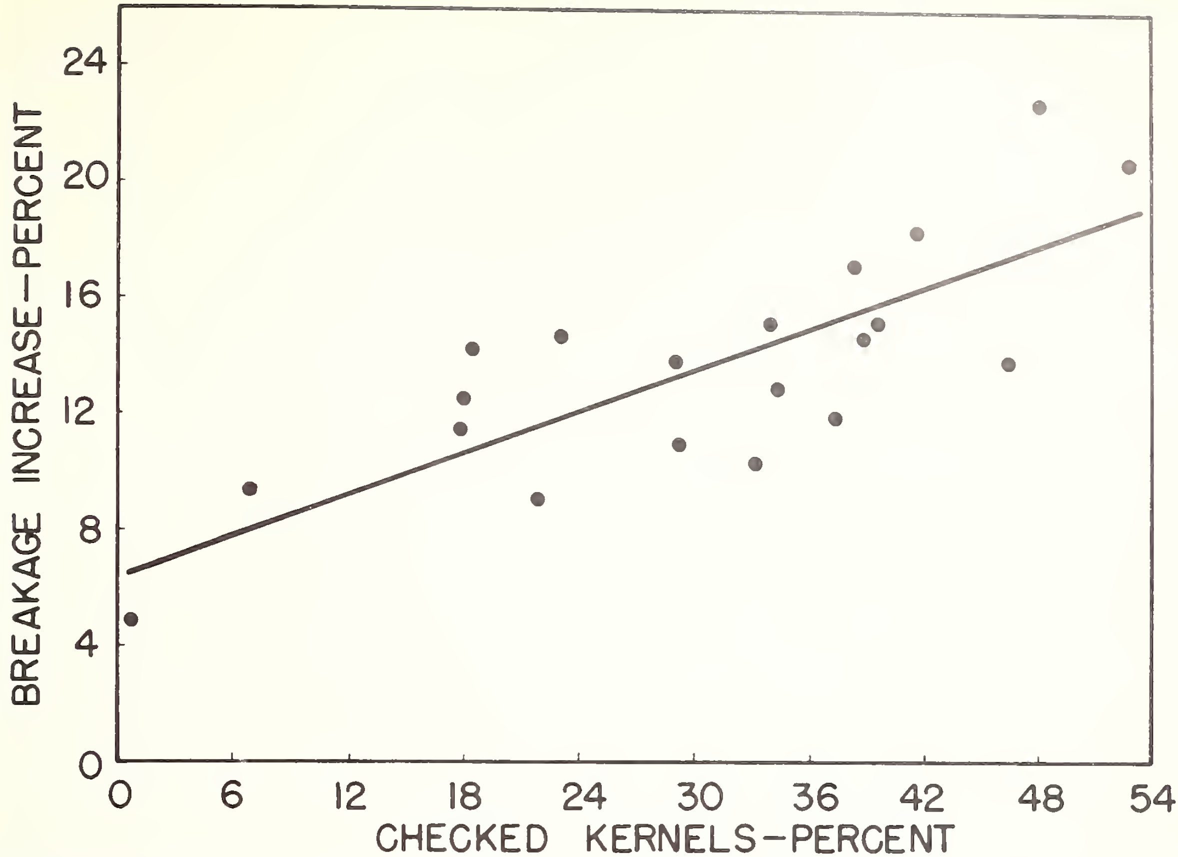

Figure 9.--Relation between stress cracks and breakage in corn, based on the increase in breakage of corn dried with heated air over that dried with unheated air. The correlation coefficient of this relationship is 0.79 and the standard error from the regression $\pm$ 2.58 (percent breakage).

STRESS-CRACK DEVELOPMENT

Drying Speed

The effects of drying-air temperature and flow rate were combined into an expression of drying speed represented by the moisture reduction in percentage points per hour. The effect of the drying speed on the development of checked kernels is shown in figure 10 for the data from the 1961 field tests. Data from the batch tests were not included, since the drying speed was available only as a batch average and the batch included both overdried and underdried kernels. In the continuous-flow tests, the total moisture removed divided by the time in hours required for the grain to pass through the dryer gave the rate of moisture reduction or drying speed. The data in figure 10 show that drying speed accounted for much of the difference in the number of checked kernels in dried samples. The solid dots representing corn dried from near 30 percent are mostly above the line in figure 10. All but one of the tests where corn was dried from near 20 percent fell below the line. Thus, the amount of moisture reduction as well as the speed of drying contributed to stress-crack formation.

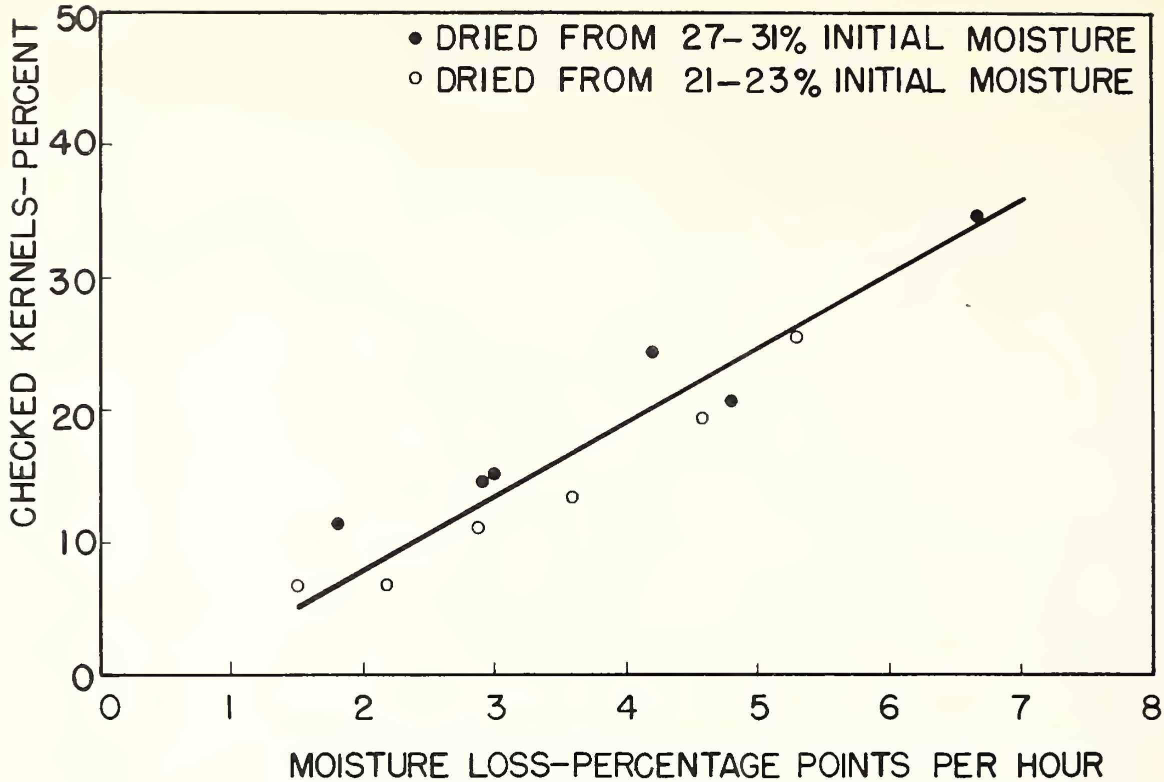

Figure 10.--Effect of drying speed on development of stress cracks in corn. The correlation coefficient between these two variables is 0.94 and the standard error from the regression was $\pm$ 2.90 (percent checked kernels).

A 1960 laboratory study compared stress-crack development during drying of ear and shelled corn from 20 to 14 percent, and demonstrated the importance of drying speed in stress-crack formation. The shelled corn dried 7 to 12 times faster than ear corn. When dried at 160° F., 100 percent of the kernels of shelled corn had multiple stress cracks, but only 3 percent of the kernels of ear corn had multiple cracks. In fact, more stress cracks formed in shelled corn dried at room temperature (80° F.) than in ear corn dried at 160° F.

Drying shelled corn with air temperatures of 290° F. resulted in puffing of the corn, as discussed in the section on breakage. The internal structure of the puffed kernel was changed sufficiently that the development of stress cracks was reduced. Three samples of 30-percent corn dried in the laboratory at 290° F. had only 10.7 percent checked kernels, while 6 samples dried at 240° and 190° F. averaged 43.8 percent checked kernels (see appendix table 3). The puffed samples had a test weight 5.5 pounds lower per bushel than the same corn dried with 140° F. air. When drying from initial moisture levels near 30 percent, puffing started at drying speeds of 8 to 10 percentage points per hour.

Laboratory Tests Indicate When Stress Cracks Develop

In laboratory tests conducted in 1961, most of the stress cracks developed when the corn was drying through the range of 19 to 14 percent (see appendix table 4). These tests were made on 22-percent corn dried with 160° F. drying air. Drying through the range of 19 to 14 percent produced more multiple stress cracks than a 5-percent moisture reduction from 21 to 16 percent or from 15 to 10 percent. (In these tests, the checked kernels were included with the multiple stress cracks.) Drying, other than with 160° F. air, was at room temperature. Drying from higher moisture levels or with different drying air temperatures may or may not show the same critical moisture range for stress-crack development.

All test samples had more stress cracks after cooling than immediately after drying. In fact, it was possible to hear the stress cracks forming in dried samples as they were cooled.

The 1962 laboratory tests indicated the value of slow cooling in the prevention of stress cracks. An average of 43 percent of the kernels in 12 samples dried at 190° and 240° F. had a checked stress-crack pattern when the corn, after drying, was cooled rapidly with forced room air. This compares to only 3 percent when the corn was cooled slowly in vacuum bottles (see appendix table 3).

In three field tests in the fall of 1962, corn was moved from the continuous dryer into storage bins before it was cooled. The hot corn was cooled slowly by aeration. These tests confirmed that slow cooling was helpful in preventing stress-crack formation.

Other Factors in Stress-Crack Development

The results of some special tests in the laboratory, together with observations made during stress-crack evaluation, gave further insight into the conditions that lead to stress-crack development.

In one test, corn was placed in pint metal containers, with thermocouples inserted through the lids to measure the sample temperature. The covered samples were heated to 230° F. in an oven. Since no moisture was removed from the corn during the heating process, very little stress-crack development occurred, even when the sample was cooled rapidly.

An exploratory test showed that freezing of wet corn will, under some conditions, cause hairline cracks in the endosperm that are sometimes difficult to distinguish from stress cracks caused by drying. Also, soaking dry corn in water caused it to swell fast enough to form internal fissures. However, samples rewetted in water-saturated air did not develop stress cracks.

Large round kernels were more subject to stress cracks than flat kernels.

X-rays showed no stress cracks undetected by the candling process. In fact, the cracks that were readily seen with bright light were more difficult to distinguish in the X-ray pictures.

APPLICATIONS

Stress-Crack Determinations

Stress-crack evaluation is useful as a rapid method of detecting corn that has been artificially dried. The severity of the drying treatment is indicated by the number and type of stress cracks. As drying stress increases, single cracks develop into multiple cracks or checks.

None of the dried test samples had an equal distribution of single cracks, multiple cracks, and checked kernels. Large numbers of checked kernels and kernels with single or no stress cracks in the same lot might indicate that overdried and underdried corn were mixed.

There is some relationship between stress cracks and germination. A high percentage of checked or crazed kernels in a corn sample almost assures low germination. However, the absence of stress cracks does not assure high viability, since low germinating power may be caused by conditions other than those that cause stress cracks. Therefore, stress-crack determination may be used as a rapid method of detecting certain lots of corn unsuitable for commercial uses requiring corn with high viability. Dry millers expect less yield of large grits in dried corn with stress cracks. Small grits are less valuable than large grits.

Breakage Tests

The moisture content and temperature of the sample at the time the test is made influence the breakage perhaps even more than usual variations in the drying treatment. Figure 11 shows the effect of sample moisture on the tendency of shelled corn to break. The kernel became more friable as the moisture content was reduced. When moisture was reduced below about 13 percent, breakage increased rapidly. For this reason, all breakage comparisons were at moistures of approximately 13.5 percent. However, when breakage tests are used to indicate the breakage expected when the corn is handled commercially, the moisture level is an important test factor and should be representative of the lot of corn under consideration.

Lowering the temperature of the corn sample tested made it more brittle. When the temperature of some samples of corn was reduced from 84° to 42° F., the amount of breakage doubled. All the comparisons reported were made when the sample temperature was about 80° F. Here again, if the breakage test is used to predict breakage in a lot of corn to be handled, the test sample should be at the same temperature as the mass of corn to be handled.

CAN BREAKAGE AND STRESS CRACKS IN ARTIFICIALLY DRIED CORN BE REDUCED?

Test results indicated those factors in the artificial drying process that are related to physical changes in the corn kernel. Drying goes hand in hand with harvesting at high moistures. Mechanical damage during harvesting contributes to breakage and may be reduced by improving harvesters or by delaying harvest until corn is at a lower moisture level.

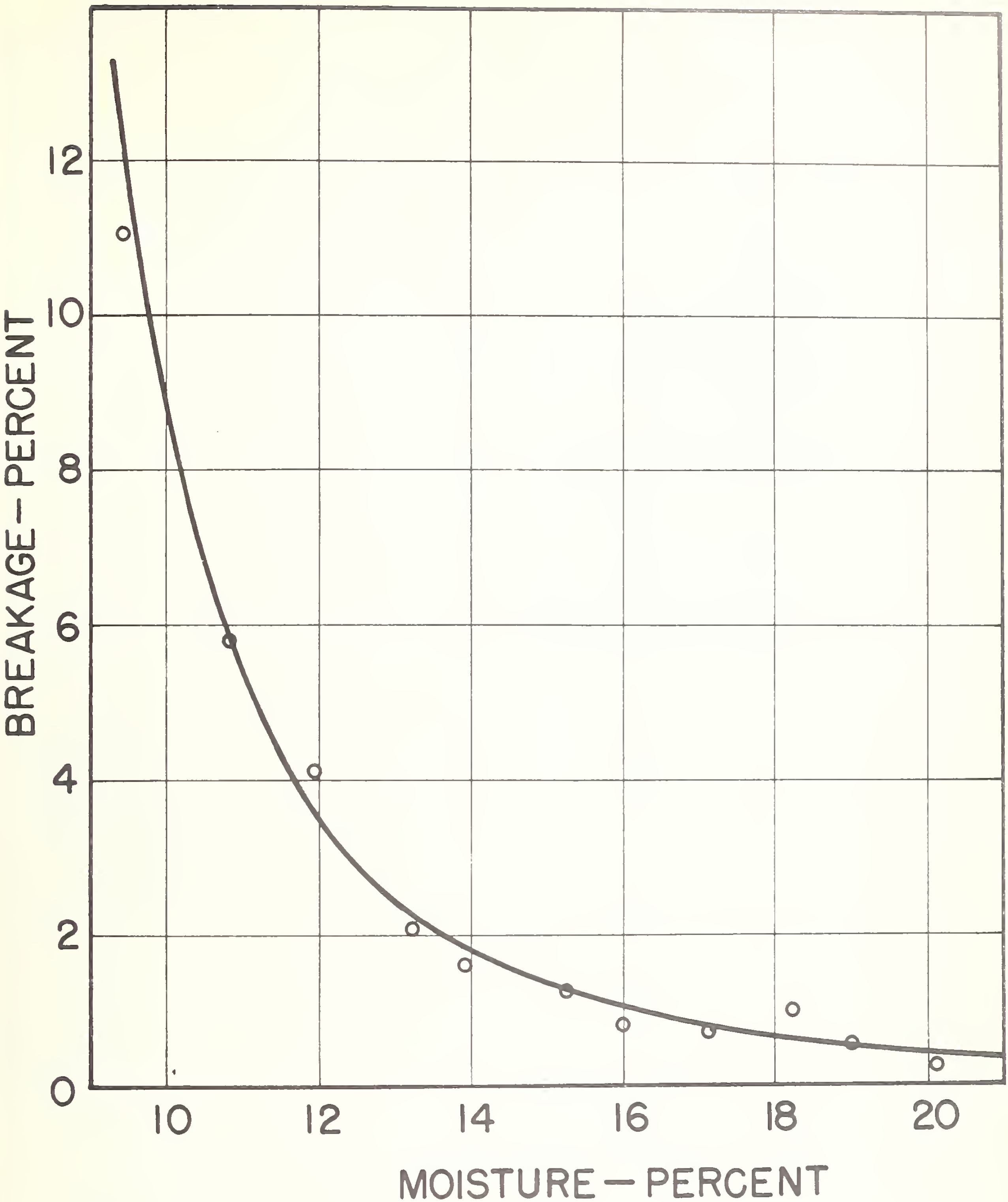

Figure 11.--Effect of moisture content of sample on breakage of corn.

Avoiding overdrying and avoiding handling shelled corn while cold will reduce its susceptibility to breakage. Slow drying reduces stress-crack development. This applies particularly to drying through the moisture range from 19 to 14 percent.

Delaying cooling until after a tempering period appears beneficial. Applying steam to the corn immediately after drying apparently relieves the stress by wetting the outside of the kernel and making it less friable. Perhaps the hot corn provides its own steam during the tempering period. This steaming process may be more beneficial than the time delay in cooling.

Any pretreatment of the corn that will increase the ease of moisture transfer from the kernel to the drying air should allow the corn to be dried faster without increasing drying stress. Pretreatment should be investigated along with various posttreatments that will relieve drying stress before the stress cracks form.

APPENDIX

Stress-Crack Evaluation

A 50-gram sample of corn was prepared for stress-crack evaluation by first removing all foreign material. All broken, cracked, or otherwise physically damaged kernels were removed. Kernels with a "chalky" endosperm or other impairments that prevented the endosperm from being easily examined were also removed. Only those kernels that were not damaged and could be readily examined by candling were used.

The sample was examined for stress cracks by candling each kernel individually. The light for candling was passed through a small square glass-covered opening in a box containing a 150-watt incandescent lamp. The kernels were examined by holding the germ side toward the light source. It was often necessary to change the position of the kernel to see all the cracks. Samples usually contained from 130 to 150 whole kernels and took 15 or 20 minutes to inspect. As the sample was inspected, the kernels were sorted into three stress-crack categories--single, multiple, and checked. The percent of kernels in each category was then computed.

Breakage Determination

Samples of corn evaluated for breakage were first checked for moisture content with an electric meter. Whenever the samples were not at approximately 13.5 percent moisture content, they were conditioned in an atmosphere of about 80° F. and 65 percent relative humidity. (Relative humidity was varied somewhat for corn dried at different temperatures.) Once the samples reached 13.5 percent, they were placed in plastic jars and sealed.

The conditioned samples were screened (with a 1/4-inch round-hole sieve) to remove broken kernels. The samples were then passed through a mechanical divider and reduced to 100 grams for the breakage test. After the prescribed time in the test device, the corn was removed and screened with a 12/64-inch round-hole sieve. The corn remaining on top of the sieve was weighed and the loss in weight calculated as the percent breakage.

Three types of test devices were used to evaluate breakage. A modified food blender was used in all four drying seasons. In 1961, a modified peanut splitter and a breakage tester manufactured commercially were also used. The peanut splitter was not used in 1962, but tests were continued with both the commercial tester and the food blender.

The breakage data reported were obtained with the modified food blender. This tester was developed by the Grain Division of the Agricultural Marketing Service, U. S. Department of Agriculture. The metal blades on the blender were replaced with a centrally mounted piece of plastic tubing approximately 2 inches long. A square pint Mason jar was used as the sample container. The blender was operated for 30 seconds at a speed of around 10,000 rpm.

A breakage tester similar to the peanut splitter developed by Dickens 4/ was built and used in 1961. Kernels were dropped into a hole located in the center of a 9-inch impeller made of 7/8-inch-diameter brass tubing, and revolved at approximately 1,765 rpm. The impeller was centrally located in a 12-inch-diameter steel cylinder with a 5/16-inch wall thickness. The kernels were dropped individually into the rotating impeller by a vibrating feeder and thrown outward to strike the wall of the cylinder. About 5 minutes were required to run a breakage test.

The commercial breakage tester used was similar in operating principle to the modified food blender. The device was equipped with a self-timer, and operated for 2 minutes at approximately 1,790 rpm. The sample was dropped into a closed cylindrical container where a specially designed motor-driven impeller threw the kernels against the top and sides of the container.

The food blender treated the samples more severely than the other devices, and the amount of breakage was greater. The plastic impeller used was subject to continual wear, and caused some variation in results. However, the impeller was replaced before the wear became extensive. The time required to run a breakage test with the modified peanut splitter was longer than with the other testers. All of the testers used showed the same trends in breakage among the samples tested.

4/ Dickens, J. W. Kernel Splitter and Inspection Belt for Peanuts. Mktg. Res. Rpt. No. 452, USDA. February 1961.

Table 1.--Effect of artificial drying on breakage of shelled corn, field drying tests, 1960-62

Test factors compared	Average breakage	
	Control 1/	After drying
	%	%
Initial corn moisture		
17.5-23.2% (18 tests)	4.7	15.2
26.9-31.1% (18 tests)	9.8	20.1
Drying-air temperature		
140° F. (12 tests)	7.7	16.5
190° F. (12 tests)	7.2	17.1
240° F. (12 tests)	6.8	19.3
290° F. (4 tests-1962 only)	6.4	24.3
Drying method		
Continuous flow (18 tests)	7.5	18.1
Batch (18 tests)	6.7	17.2
Airflow rate (1961 tests only)		
32-37 cfm/bu. (11 tests)	8.2	15.8
62-72 cfm/bu. (12 tests)	7.9	16.4

1/ All control samples were dried in screen-bottomed trays with unheated air.

Analysis of variance showed the difference between the mean breakage after drying at the two moisture levels and the differences in the mean breakage among the three test years to be significant at the 1 percent level. Differences in the mean breakage among the three lower temperature levels and between the two drying methods were not significant at the 5 percent level.

Table 2.--Effect of artificial drying on stress-crack development in shelled corn, 1961-62 field tests

Test factors compared	Average stress-crack count							
	Control 1/				After drying			
	Single	Multiple	Checked	Total	Single	Multiple	Checked	Total
	%	%	%	%	%	%	%	%
Initial corn moisture								
17.5-23.2% (12 tests)	13.6	4.5	0.3	18.4	9.2	61.2	22.8	93.2
29.6-31.1% (12 tests)	42.7	12.2	0.7	55.7	3.8	61.1	32.9	97.8
Drying-air temperature								
140° F. (8 tests)	32.5	7.2	0.3	40.0	10.5	64.9	20.2	95.6
190° F. (8 tests)	25.6	10.0	0.6	36.2	4.3	64.0	29.6	97.9
240° F. (8 tests)	26.4	8.0	0.5	34.9	4.6	54.5	33.9	93.0
290° F. (4 tests-1962 only)	10.7	0.9	0.1	11.7	6.9	44.8	40.2	91.9
Drying method								
Continuous flow (12 tests)	30.0	10.8	0.5	41.3	6.7	61.0	29.7	97.4
Batch (12 tests)	26.3	6.0	0.4	32.7	6.3	61.3	26.1	93.7
Airflow rate (1961 tests only)								
32-37 cfm/bu. (11 tests)	40.8	15.2	0.6	56.6	5.8	72.1	15.7	93.6
62-72 cfm/bu. (12 tests)	30.5	11.0	0.4	41.9	3.6	73.2	20.0	96.8

1/ Control samples were dried in screen-bottomed trays at room temperature.

Analysis of variance showed the differences between the mean percent of checked kernels after drying at the two moisture levels, among the three lower temperature levels, between the two drying methods, and between the two test years, all to be significant at the 1 percent level.

Table 3.--Stress cracks and breakage in dried corn, 1962 laboratory tests 1/

Drying-air temperature	Initial moisture	Checked kernels		Breakage	
		Cooled rapidly 2/	Cooled slowly 3/	Cooled rapidly	Cooled slowly
°F.	%	%	%	%	%
290	30	4/ 10.7	0.1	16.7	6.4
	18	66.3	2.5	19.3	9.5
240	30	44.0	0.6	9.6	5.4
	18	45.1	3.2	15.3	10.8
190	30	43.7	2.4	8.8	4.2
	18	41.1	3.5	14.1	8.8
140	30	37.4	--	13.2	--
	18	18.2	4.7	14.2	10.7

1/ Average of three tests at each temperature and moisture level.
2/ Cooled immediately after drying with forced air at room temperature.
3/ Placed in vacuum bottle for 24 hours after drying.
4/ Kernels puffed from rapid drying.

NOTE: Corn used for 30% tests was hand-shelled and that used for 18% tests machine-shelled. Drying was stopped at about 14% moisture content.

Table 4.--Effect of artificial drying on stress-crack development in shelled corn, laboratory drying tests, 1961

Moisture reduction with 160° F. air 1/ from - -	Kernels with multiple stress cracks
%	%
22-18	5.0
22-16	86.9
22-14	100.0
22-12	98.2
22-10	98.1
21-16	94.0
19-14	97.5
17-12	89.1
15-10	23.1
14-12	26.4

1/ Initial moisture content of all samples before treatment was 22 percent. The samples listed in column 1 with initial moistures below 22 percent were dried to those initial figures by natural circulation of room air at about 80° F. and then were treated with 160° F. air. Similarly, all samples were dried to a final moisture of approximately 12 percent. Those samples listed in column 1 with final moisture contents above 10 to 12 percent were dried from the final figures shown to 12 percent by natural circulation of room air at about 80° F. after being treated with 160° F. air. Stress cracks were counted at the moisture level of 10 or 12 percent.